Exhibit D

THE ROLE OF POLYCHLORINATED BIPHENYLS IN ELECTRICAL EQUIPMENT

PREFACE

On Thursday, December 16, 1971, Mr. J. F. McAllister, Manager, Product Quality, General Electric Co., offered to submit to Dr. Edward J. Burger, Jr., of the U. S. Office of Science and Technology by Monday, January 3, 1972, a report describing the essential role that polychlorinated biphenyls play in certain types of electrical equipment. The task of preparing this report was undertaken on Monday, December 20, by the following group of General Electric Company scientists and engineers:

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Material on capacitors was prepared by Mr. Boudreau; on transformers by Mr. Raab; and on related scientific and editorial matters

INTRODUCTION

Polychlorinated biphenyls (PCB) have been used in a wide variety of industrial and consumer applications over the past 40 years, but it was only recently that evidence began to appear that these materials had been widely dispersed throughout the environment. By letter dated February 18, 1970 the Monsanto Company, sole US producer of PCB's, notified all of its customers of "the potential problem of environmental contamination" by these liquids and recommended "that all possible care should be taken in the application, processing, and effluent disposal of these products to prevent them becoming environmental contaminants." Monsanto has begun a program to discontinue sales of PCB's for use in paints, plasticizers, specialty inks, adhesives, paper coatings and all other open-system applications.

The Monsanto Company has declared, however, that it will continue to sell PCB's for closed-system electrical uses. This decision is a tacit recognition of the important role that PCB's play in the safe, reliable, and efficient delivery of electric power from the generating plant to the user. In the spate of published reports and statements that have appeared in recent years on PCB's there has been no meaningful exposition of this role of PCB's in electrical equipment -- why, where, and how they are used; what alternatives are available; and what the consequences would be to the users of such equipment if PCB's were no longer available. We hope that this report will provide such an exposition.

BACKGROUND

PCB's are used by the electrical industry as components of certain types of transformers and capacitors. The nature and function of those devices are described in the separate sections of this report devoted to them. At this point it is sufficient to say:

1. Transformers are devices for converting electrical power from one voltage and current level to another, and the conducting parts of these devices must be separated from each other by a suitable insulating medium.

2. Capacitors are devices for storing electrical energy through the physical separation of charged metal surfaces by an insulating medium.

Prior to 1930 the most commonly used insulating medium was mineral oil. The early 1930's saw the commercial development of insulating liquids that were mixtures of synthetic chlorinated aromatic hydrocarbons, principally various polychlorinated biphenyls. By controlling the composition of these mixtures, the manufacturer could obtain desired combinations of thermal, chemical and dielectri properties that resulted in insulating liquids with much greater oxidation and fire resistance than mineral oils. During the past 40 years these liquids have become widely used in certain types of transformers and capacitors and are recognized as a distinct class of insulating materials designated by the international term "askarel". The definition of the term "askarel", the compositions of the liquid that comprise this class of materials, and the various trademarks by which they are known commercially are described in the following section headed "Askarel".

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The particular askarels used in transformers and capacitors are different; so also are the reasons for, and the extent and consequences of, their use in these two types of electrical equipment. However, certain general comments can be made at this point concerning their use in both types of equipment:

1. Askarel-insulated transformers and capacitors are delivered to customers as sealed units from which there is no escape of askarel under normal operation during their expected lifetimes of 10 to more than 30 years. However, certain types of equipment failures can rupture the case and permit the loss of some askarel to the environment. Such failures occur at a rate of about 0.02% of the units in service per year.

2. PCB's can get into the environment during the manufacture, delivery, improper use, maintenance, repair, and disposal of transformers and capacitors. In addition to specific control measures instituted by individual manufacturers and recommended by them to the equipment users, the American National Standards Institute has established ANSI Committee C107 on Use and Disposal of Askarel Used in Electrical Equipment. Its memberships (see Appendix 1) is divided into separate working groups on transformers and capacitors which will recommend national standards and procedures necessary to prevent the loss of PCB's to the environment at all stages from equipment manufacture through ultimate disposal.

8 3. The record of reliable and safe performance that askarel-insulated transformers and capacitors have

compiled during the past four decades is reflected in the various codes, standards, and regulations that now effectively require or encourage the continued use of askarel-insulated equipment in many applications.

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ASKAREL

Definitions

1. A synthetic nonflammable insulating liquid which, when decomposed by the electric arc, evolves only nonflammable gaseous mixtures.

(From the National Electrical Code 1971 and the American National Standards Institute C-42 series, "Definitions of Electrical Terms.")

2. The term askarel generally describes a widely used, broad class of nonflammable synthetic halogenated hydrocarbon insulating liquids used as electrical insulating media.

Askarels of various compositional types are used. Under arcing conditions the gases produced, while consisting of predominantly non-combustible hydrogen chloride, can yield varying amounts of combustible gases depending upon the askarel type.

Insulation systems incorporating these askarels and cellulosic or other organic materials may, when arced, produce gaseous mixtures which are moderately flammable.

(From ASTM (American Society for Testing and Materials) Method D 2283-71, Part 29, 1971 issue; will also appear in the 1972 issue of the IEEE (Institute of Electronic and Electrical Engineers) "Guide for Acceptance and Maintenance of Transformer Askarels in Equipment." Adoption was also recommended to the International Electrotechnical Commission by its Subcommittee 10B (Insulating Liquids Other than Hydrocarbon Oils) of Committee 10 (Liquid and Gaseous Dielectrics) as reported in item number 9 of minutes RM 1364/SC 10B. March 1971.)

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Compositions

Polychlorinated biphonyls are derivatives of the hydrocarbon, biphenyl, which has the chemical formula $C_{12}H_{10}$. From one to ten of the hydrogen atoms in a molecule of biphonyl can be replaced by chlorine atoms, and the chemical identity of the resulting chlorinated compound depends both on the number of chlorine atoms that have been introduced into the molecule and on the specific sites in the molecular structure at which they are introduced.

The commercial material manufactured by Monsanto under its registered trademark Aroclor consists of mixtures of these specific chlorinated compounds. They are usually identified by the weight percent of chlorine in the total mixtures, e.g. Aroclor 1254 contains 54% chlorine. The Aroclors commonly used in the electrical industry are Aroclors 1260, 1254, and 1242.

Aroclor 1242, used primarily in capacitors, contains about 7% of pentachlorobiphenyls and higher. In September 1971 Monsanto introduced a new capacitor-grade askarel, Aroclor MCS-1016, which is essentially Aroclor 1242 that has been specially processed to reduce the content of pentachlorobiphenyle and higher to less than 0.4%.

As a general rule, the nonflammability of liquid PCB's, their vapors, and their arc-formed gaseous products is greater the higher the degree of chlorination of the liquid. Studies by Monsanto suggest that the resistance of PCB's to degradation in the environment may also increase with increasing chlorine content. Analytical methods for low levels of PCB's (reported in parts per million or parts per billion) in marine, aquatic, and wildlife environments do not always identify the specific compounds that are present, but in its letter of February 19, 1970 to its customers, Monsanto stated that "PCB's with a chlorine content of less than 54% have

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not been found in the environment and appear to present no potential problem to the environment."

Trademarks

The following trademarks are used by electrical manufacturers to designate the askarels used in their products:

Manufacturer	Trademark
Aerovox	Hyvol
Allis-Chalmers	Chlorextol
American Corp.	Abestol
Cornell Dubilier	Dykenol
General Electric	Pyrenol
Kuhlman Electric	Saf-T-Kuhl
McGraw Edison ~~Line Material~~	Elemex
Sangamo Electric	Diaclor
Wagner Electric	Noflamol
Westinghouse Electric	Inerteen

Toxic and Biological Effects of PCB's

Systematic investigations of the toxic and biological effects of PCB's have been undertaken only within the past few years, and the description and evaluation of the results is beyond the scope of this report. Some investigators suggest that reports of certain toxic reactions may be caused by highly poisonous compounds (e.g. chlorinated dibenzofurans) found to be contaminants in some PCB preparations. In the United States, medical records show that over a nearly 40-year period the only adverse health effects experienced by US workers exposed to PCB's, either during the manufacture of these liquids or of electrical equipment containing these liquids, have been limited to occasional cases of non-chronic chloracne or other temporary skin lesions or irritations.

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TRANSFORMERS

Definition

A transformer is a device for transferring electrical energy from one alternating current circuit to another by electromagnetic means. It has no moving parts and performs its function by linking two electric current-carrying circuits (the coils, usually copper wire) via a common magnetic flux carrying-circuit (the core, usually a special grade of iron). A transformer may be designed to effect a change in voltage or current from one circuit to the other or simply to obtain electrical energy from one electrical circuit without making a conductive connection between it and a second electrical circuit.

The transmission of electrical energy from one point to another is essentially the transmission of a required number of kilovolt-amperes (kva). By means of transformers the kva's may be generated at a low voltage suitable for the windings of generators, stepped up to higher voltages and lower currents suitable for transmission of electricity over long distance wires, and then at the desired destination stepped down to a lower voltage and larger current suitable for utilization by electrically powered equipment.

The almost universal use of the alternating current system for the transmission and distribution of electrical energy is largely due to this ability of transformers to link up circuits of different voltages and currents. Thus the generator, the transmission lines, the secondary distribution system, and finally the great variety of ultimate loads can each be operated at the voltage most suitable to its particular function. Without this unique ability of the transformer to adapt the circuit voltage to the individual requirements of the different parts of the system, the enormous development and progress in the transmission and distribution of electrical energy during the past 80 years would not have been possible.

Why Askarels are Used in Transformers

The coils and core of most transformers are enclosed in sealed metal tanks that are filled with an insulating liquid, usually mineral oil. Under certain conditions of sudden power surges high-current electric arcs are produced inside the transformer which can generate and ignite flammable and explosive gas mixtures formed from the mineral oil and other cellulosic insulating components in the transformer.

Because of the nonflammability of liquid askarels, their vapors, and their arc-formed gaseous products, transformers filled with askarels are free of these fire and explosion hazards and may be used in locations where failures of oil-insulated transformers would present a potential danger to life and property. This safety factor is the only advantage that askarel-insulated transformers have over oil-insulated transformers of the same size and rating. The density of askarels is about 1.7 times that of mineral oil, so askarel-insulated transformers are heavier than their oil-filled counterparts. Askarels themselves are more expensive than mineral oils, and their solvent characteristics require the use of more expensive insulation components on the internal parts of the transformer, so the complete units are more expensive.

As a consequence, askarel-insulated transformers have captured only those market applications (less than 5%, but growing) where considerations of safety and reliability are paramount. Their use in such applications is usually required or encouraged by the provisions of electrical codes, fire underwriting policies, or governmental regulations.

Note: Prior to the mid-1950's the liquid used in askarel-insulated transformers was a 50-50 weight mixture of Aroclor 1260 (60% chlorine) with trichlorobenzenes; then the benzene component was changed to a mixture of tri- and tetrachlorbenzenes; and in 1971 the Aroclor component was changed to Aroclor 1254 (54% chlorine).

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Types and Applications of Askarel-Insulated Transformers

There are two broad classifications of transformers: power transformers, which are used to step up voltages; and distribution transformers, which are used to step down voltages. The many types of transformers that are included within these two classifications are listed in Appendix 2. The applications that accompany the listing apply only to those units of a given type that are manufactured with askarel as the insulating liquid. Most units of the types listed are still oil-insulated.

We estimate that the total number of askarel-insulated units that have been put into service in the United States since 1932 is 125,000, and virtually all of these units are still in service. The lifetime-before-failure is often longer than 30 years, and almost all units that do fail are rebuilt and returned to service. The current production rate of new askarel-insulated transformers units is about 5,000 per year.

Most of these transformers are located inside public, commercial, or industrial buildings; on the roof tops of such buildings; or in close proximity to such buildings, and require no special enclosures other than what are necessary to prevent accidental hazardous mechanical or electrical contact of persons with the equipment. However, the National Electrical Code does specify vaults for the indoor installation of askarel-insulated transformers rated more than 35,000 volts. Askarel-insulated transformers are limited by the electrial properties of these liquids to ratings below 69,000 volts.

The amount of askarel used in various types of transformers ranges from 40 to 500 gals. (516 to 6,450 lbs.) with an average of about 235 gals. (3,032 lbs.). During 1968, the last complete "normal" year for the electrical industry, the total amount of

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PCB's used in transformers was approximately 1.3 million gallons (8.4 thousand tons).

Present Alternatives to Askarel-Insulated Transformers

If PCB's were to be no longer available for closed-system electrical uses -- as they are no longer available from Monsanto for open-system applications -- what alternatives to askarel-insulated transformers could now be supplied by the electrical industry, and what would be the effect upon the user should askarel-insulated transformers no longer be available either as new or replacement units?

The only present alternatives to askarel-insulated transformers are oil-insulated transformers or dry-type transformers (either those open to the atmosphere or those that are gas-filled and sealed)

A. Oil-insulated transformers

1. If one disregards safety considerations, there are no technical reasons why oil-insulated transformers could not be directly substituted for askarel-insulated transformers. The size of the unit would be unchanged; the weight and cost would be less.

2. There are legal restrictions to such a direct substitution.

a. Some local regulations (e.g. Chicago) prohibit the use of oil-insulated units in certain locations where askarel-insulated units are allowed.

b. Where oil-insulated transformers would not be specifically prohibited as on-site replacements for askarel-insulated units, the National Electrical Code imposes special restrictions upon their mode of installation. Although

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35,000 volts must be installed in vaults, all oil-insulated transformers require vaults, except that alternative fire protection arrangements are permitted for units rated not over 600 volts. Assuming that space were available inside an existing building to accommodate these special auxiliary safety provisions, the cost of their construction could range from $5,000 to $50,000 per transformer.

c. Oil-insulated units can be installed outdoors if they are suitably isolated from flammable structures or if these structures are suitably safeguarded against fires originating in the transformers. The power output must then be brought to the point of use inside the building via cables or insulated buses, and the cost of cable and bus installation could also range from $5,000 to $50,000 per transformer. The outdoor transformer would have to be of a higher rating than the indoor one it would replace because of voltage drop and consequent power losses in the cable or bus runs.

B. <u>Dry-type transformers</u>

In most locations, dry-type transformers (either those open to the atmosphere or those that are gas-filled and sealed) could not be directly substituted for askarel-insulated transformers. There are several restrictions to such a direct substitution:

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1. The provisions of the National Electrical Code are more stringent for certain classes of dry-type transformers than for comparable askarel-insulated units.
2. Present technology is not available for designing and manufacturing reliable dry-type transformers above 2500 KVA and/or 15 KV.
3. The reliability of dry-type transformers is less than that of comparably rated liquid-insulated transformers. Oil- and askarel-insulated units show much greater resistance to switching and lightning surges than do dry-type units. An EEI survey of failures in network transformer banks showed a 7% per year failure rate for dry-type units compared to 0.2% for liquid-insulated units. Furthermore, liquid-insulated transformers have a much greater overload capability. Many liquid-insulated units can sustain a 100% overload for 8 hours and a 200% overload for 2 hours. These transformers are able to maintain continuity of electrical service during periods of temporary outage of related equipment.
4. Some dry-type transformers are larger by 10 to 30% than comparably rated liquid-insulated units, and most are more expensive.
5. Dry-type transformers are noisier by 5-10 dB than are liquid-insulated transformers.
6. Because their insides require regular cleaning, the maintenance costs for open dry-type transformers are higher than those for sealed dry-type transformers

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or for liquid-insulated transformers, which are also sealed.

7. Open dry-type transformers, which are cheaper than sealed dry-type transformers, cannot be used in certain corrosive or hazardous atmospheres, e. g. on furnaces or on electrostatic precipitators near hot stacks.

C. Summary

1. For technical or legal reasons it would be impossible to replace most askarel-insulated transformers now in service by oil-insulated units of equivalent rating and reliability without major construction changes that would be required to compensate for the fire and explosion resistance of the askarel-insulated units.

2. For certain applications and locations, dry-type transformers could replace askarel-insulated transformers, but with a significant reduction in system reliability.

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CAPACITORS

Definition

A capacitor is a device that stores electrical energy. It consists of two metal surfaces or electrodes separated by an insulating medium such as air, paper, plastic film, or oil. When a voltage is applied across the electrodes, electrostatic energy is stored in the insulating medium.

In typical industrial capacitors the electrode material is aluminum foil and the insulating medium or dielectric is paper tissue and/or plastic film, which for many applications is impregnated with a liquid dielectric. A liquid impregnant is used to fill the voids within the paper or plastic film structure, to fill the voids between sheets, and to contribute to the capacitance or charge-carrying ability of the composite. Voids must be eliminated within capacitors that are to be used above 200-300 volts, which exceeds the dielectric breakdown strength of air.

In our definition of transformers we emphasized their importance in the transmission and distribution of electrical power (kilovolt-amperes) from the generating plant to the ultimate load. If the load were purely resistive (e.g. an electric heating element) no further modification of the power supply delivered to it would be required. Other loads (e.g. induction motors) may require that a portion of the kilovolt-amperes delivered to them be used to provide a magnetizing current, which does not contribute directly to the useful power output of the load. This portion of the total kva delivered to the load is designated as reactive kilovolt-amperes (kvars). It has been found more economical to produce kvars from total kva's near the point of load rather than near the point of kva generation, and capacitors provide the most efficient way of

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effecting this transformation at the point of load.

Why Askarels are Used in Capacitors

Prior to 1930 most liquid-filled capacitors were made with mineral oil. The subsequent substitution of askarels for mineral oil made possible significant technical improvements in the size, reliability, and life of these capacitors.

A. Size

The single most important property of a liquid to be used in a capacitor is its dielectric constant (the ratio of its ability to store electrostatic energy relative to air). The dielectric constant of capacitor-grade askarel (Aroclor 1242) is 5.85 while that of mineral oil is 2.25. When capacitor tissue is impregnated with these liquids the dielectric constant of the paper-liquid composite is 6.1 for askarel and 2.9 for mineral oil. Furthermore, because of the relatively close match between the dielectric constants of cellulose, (6.6) and askarel (5.85) it is possible to stress askarel-impregnated paper to 400-500 volts/mil, while the stresses that can be applied to comparable paper-mineral oil capacitors are limited to 300-350 volts/mil. The combined effect of these technical advantages of askarels has been to permit a reduction of capacitor sizes to less than 14% of what they were in 1924. In 1965 a new dielectric system consisting of paper-polypropylene film-askarel was introduced with stress capability up to 900 volts/mil. overall. Besides favorable stress distributions, the ability of askarel to increase the dielectric strength of polypropylene

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is partly responsible for this improvement.

B. Reliability and life

Askarels are thermally and oxidatively more stable than mineral oils, and discharges, which can occur in capacitors, are less likely to generate gases from askarels than from mineral oils. The chemical stability of askarels in the presence of capacitor tissue and plastic films and the favorable stress distributions between solid and liquid referred to above have made it possible to design low-cost capacitors with a life expectancy of more than 10 years life in lighting applications and more than 20 years in electric utility applications. In each application the first-year failure rates are less than 0.2%. This level of life and reliability had not been achieved prior to the introduction of askarels. Furthermore, the non-flammability of askarels is greater than that of mineral oil, which reduces the fire hazard that might otherwise accompany those failures that result in rupture of the case.

Whereas the transformer manufacturer has had to essentially "design around" the properties of askarels in order to be able to take advantage of the safety factor that they impart to his equipment, the capacitor manufacturer has been able to "design with" the properties of askarels and obtain significant technical improvements along with the improved safety factor. As a result askarels have virtually supplanted mineral oils in more than 90% of the power and industrial

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Note: Prior to 1952 the liquid used in askarel-impregnated capacitors was Aroclor 1254 (54% chlorine); it was then replaced by Aroclor 1242 (42% chlorine), which has better electrical properties; and as noted in the "Askarel" section, in September 1971 Monsanto introduced a new capacitor-grade askarel, Aroclor MCS-1016, which is a modified Aroclor 1242. Unlike askarel-insulated transformers, the liquid in askarel-impregnated capacitors contains only Aroclors and does not contain added chlorobenzenes.

Types and Applications of Askarel-impregnated Capacitors

The principal types of askarel-impregnated capacitors and their applications are described in Appendix 3. Almost 80 million such capacitors are manufactured annually, most of them for first-time use. Unlike transformers, capacitors are not rebuilt and returned to service after failure. They are disposed of (see "Background" section, item concerning ANSI Committe C107) and replaced by new capacitors.

Capacitors used in lighting and air conditioning applications contain 0.005 to ~~[illegible]~~ 0.09 gals. (0.05 to 1.0 lbs.) of askarel per unit. The largest power capacitors contain about 6.7 gals (77 lbs.) of askarel. The most popular size contains about 3.1 (36 lbs.) The National Electrical Code requires that any installation of capacitors in which any single unit contains more than 3 gallons of combustible liquid shall be in a vault like that required for transformers. During 1968, the last complete "normal" year for the electrical industry, the total amount of PCB's used in capacitors was approximately 14.4 thousand tons.

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Present Alternatives to Askarel-Impregnated Capacitors

If PCB's were to be no longer available for closed-system electrical uses -- as they are no longer available from Monsanto for open-system applications -- what alternatives to askarel-impregnated capacitors could now be supplied by the electrical industry, and what would be the effect upon the user should askarel-impregnated capacitors no longer be available either as new or replacement units?

Possible alternatives to askarel-impregnated capacitors are capacitors impregnated with mineral oil, or capacitors impregnated with certain other liquids.

A. Mineral Oil

Replacement of askarels by mineral oil would essentially return capacitor technology to its pre-1932 level. Some specific consequences of such a replacement would be:

1. Safety. None of the possible liquid alternatives to askarels are nonflammable, and a fire hazard would be created by any capacitor failures that were accompanied by rupture of the case. Presently the use of capacitors containing flammable liquid is governed by the National Electrical Code Articles 460 and 501.

2. Size and Cost. A few specific examples will illustrate the size and cost penalties associated with a switch from askarel to mineral oil in capacitors. The most popular sized power capacitors today are rated at 200 KVAR. If mineral oil were substituted for askarel the volume of the capacitor would be quadrupled and the direct labor and material costs associated with its manufacture would increase by 70%. Today power capacitors are available in 400 KVAR

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KVAR because of increased heat dissipation problems with increased volume. In addition to increases in direct costs, the power capacitor industry would face increased capital expenses estimated at $2,000,000 to provide the increased volume of material at projected KVAR requirements.

Steel companies faced with increased size, cost and flammability of capacitor banks for induction heating furnaces would probably not install new induction heating capability. Utilities would have difficulty with substation size in crowded urban areas. An increase in the size of capacitors for air conditioning would not be critical.

In lighting applications a 3.75/.075 uf 540 VAC rating for high output applications is typical. If mineral oil were substituted for askarel, the capacitor would be 71% larger and materials would cost 46% more. Lamp ballast manufacturers would have to increase the size of the ballast to accommodate the larger capacitor. This would change the thermal performance of the unit and require U.L. approval of new ballast designs. Lighting fixture manufacturers would also face redesign costs to take larger ballasts.

3. Reliability. Users of capacitors in all application areas have come to expect long life and very low initial failure rates. The present performance standards have been achieved after many years of field testing and accelerated testing by manufacturers and users. The reliability of designs containing

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mineral oil in many applications would be uncertain. Available records show that capacitor reliability prior to the availability of askarel was only a fraction of what it is today.

4. Replacement Market. The implications of changes in capacitor size have been discussed in terms of new designs. In each major application area some capacitors are sold for replacement business. Power and induction heating capacitors are generally installed in racks of a few to thousands of capacitors. It would not be possible to make simple substitutions for failed capacitors while maintaining the system rating. In air conditioners replacement of failed capacitors might be as simple as installation of new brackets. On the other hand, tight designs might not take a larger capacitor at all. Lighting systems would be seriously affected by increases in capacitor size. Larger replacement ballasts would not fit into existing fixtures without altered mounting arrangements. It is possible that space requirements would force complete replacement of lighting fixtures for the want of a replacement ballast.

5. Material Sources. Mineral oil is currently used in a relatively small number of specialty capacitors. In this country there is a single source of capacitor-grade mineral oil with limited facilities for acid refining of crudes from a single oil field. Increased demand would require

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expanded facilities and investment and considerable development in defining technical requirements for capacitor-grade mineral oil.

Efficient use of mineral oil in capacitor designs would require higher density capacitor tissue than is currently produced in this country. At the least this would require extensive paper machine modification. Capacitor winding techniques and machines would need to be developed for winding tighter rolls.

B. Other Liquids

1. Castor Oil. The dielectric constant of castor oil is 4.5 and this material is useful as an impregnant in D.C. energy storage capacitors. However, A.C. capacitors filled with this liquid have relatively short lives and are not very stable under A.C. discharges and in the presence of water derivable from the cellulosic paper.

2. Dibutyl sebacate. This ester is especially useful in high frequency parallel plate capacitors because of its low, flat loss characteristics over a broad frequency range. In this type of construction the liquid is the sole dielectric material. When used in conjunction with paper, this ester is also unstable.

3. Silicone Fluids. These materials have a dielectric constant of 2.7 and would generally be subject to the same disadvantages as mineral oil.

C. Alternative Designs

In addition to liquid dielectric substitutes, alternatives

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to the paper-liquid dielectric might be considered. These would involve the use of plastic film coated with aluminum foil or vapor-deposited aluminum as electrodes. Since the free volume of the system is less than that of paper the capacitance of the system is less dependent on the dielectric constant of the liquid and the stress distribution between the plastic films and low dielectric constant liquids is more closely balanced. Such dielectric systems are difficult to construct completely free of voids. It is expected that several years will be required to achieve the required level of reliability in such dielectric systems.

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POSSIBLE DEVELOPMENT OF NEW INSULATING LIQUIDS

The cost of askarel liquids is about $2.00 per gallon, compared to about $0.30 per gallon for mineral oil. Thus, long before there were any environmental concerns about PCB's there was a strong economic incentive to find other less-expensive insulating liquids with the desirable characteristics of askarels. Since the 1930's, at least 10 major chemical or electrical companies have invested large amounts of time and money in this search, all with no success. There are today no fluids that can be used as one-for-one replacements for PCB's.

The continued search for new fluids would probably start with fluorochemicals. Fluorochemicals are nonflammable, nontoxic, and as far as is presently known represent no environmental hazard. High-boiling fluorochemicals might thus be potential replacements for PCB's. Considerable laboratory study, over at least a one-year period, of the physical, chemical, and dielectric properties of these materials would be required in order to identify specific candidate materials.

At least another year would be required to develop a finished product based upon a fluorochemical. On one hand, the physical and dielectric properties would certainly be sufficiently different so that substantial engineering redesign by electrical manufacturers would be required to accommodate a fluorochemical. On the other hand, a one-year lead time is needed to construct a chemical plant to produce the identified fluorochemical in the millions of pounds that would be required per year. Furthermore, a significant program of environmental testing would be needed to ensure that the new material was indeed not an ecological hazard. The foregoing are all highly optimistic time estimat

The cost of manufacturing fluorochemicals is inherently high. Prices of high-boiling liquids are $10 - 15 per pound, or higher. At best one would hope

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that in sufficient volume the price might approach that of Teflon, currently $3 - 4 per pound. Even this optimistic figure is approximately twenty times the cost of PCB's, and since the value of PCB in a transformer is roughly one-tenth the total value of the transformer, the total cost of a fluoro-chemical-insulated transformer would be at least three times that of an equivalent askarel unit.

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Appendix 1

Membership of ANSI Committee C107 on Use and Disposal of Askarel

Used in Electrical Equipment

Number of Representatives	Organization Represented
2	Department of the Army
2	Environmental Protection Agency
1	U.S. Department of Agriculture
1	Tennessee Valley Authority
1	General Services Administration
1	National Bureau of Standards
2	Certified Ballast Manufacturers Association
1	Edison Electric Institute
1	Institute of Electronic & Electrical Engineers
5	National Electrical Manufacturers Association
2	Monsanto Company
2	Commercial Waste Disposal Companies
1	Engineering Consulting Firm
1	Capacitor Manufacturer Serving as an Independent Member

Appendix 2

Types of Askarel-Insulated Transformers

A. Distribution Transformers

1. Network (up to 2500 KVA)

2. Single- and three-phase (up to 2500 KVA)

3. Pole-mounted and station (up to 500 KVA)

The application of these transformers in power distribution systems places a great premium upon their reliability and high overload capability (which they share with comparable oil-insulated units): such as 100% overload for 8 hours and 200% overload for 2 hours.

4. Precipitation (high voltage DC)

These transformers are part of the power supply for electrostatic precipitators, which are gaining increasing use in preventing air pollution by particulate matter. They are generally installed close to hot gas stacks in an atmosphere that would be a fire hazard to oil-insulated transformers and a corrosion hazard to open dry-type transformers. Sealed dry-type transformers are impractical for high voltage DC.

B. Power Transformers

1. Secondary substation

a. Load center units

b. Secondary substation generation units

c. Switchboard units

d. Integral units

e. Motor control units

These 5 comprise the largest group of askarel-insulated transformers, and they find widespread application in the automobile, paper,

chemical, textile, steel, nonferrous metal, cement, mining, and petroleum industries. They are used in commercial and public buildings, such as schools and hospitals; in defense and nuclear energy installations; and by private and public utilities.

2. Master unit substation
3. Primary unit substation
4. Limited ampere substation
5. Industrial furnace

These transformers are used in the hot, dirty atmosphere in proximity to glass melting and induction furnaces, which require high current, low voltage power supplies (more than 2500 KVA at no more than 13.8 KV). Existing technology does not permit construction of sealed dry-type transformers for these power ratings.

6. Rectifier

These transformers are used for large rolling mills and DC industrial power supplies, and are covered by the same comments given for industrial furnace transformers.

7. Transportation
   a. Third rail

      These transformers are used for rapid transit systems, and are basically serving a rectifier function.

   b. Locomotive

      Prior to 1932, all on-board transformers were open dry-type. Because of problems with them, railroads went to askarel-insulated transformers. The changes in locomotive design since the 1930's would not now accomodate open dry-type transformers as replacements

for askarel units. A recent trend has been to replace askarel by oil units, and this will continue unless new DOT regulations require nonflammability.

8. Multiple-unit car (MU)

These transformers are mounted under the flat-bed of passenger cars. They ride along in this location, about 8 inches above the rail, at speeds up to 150 mph. The transformer must be ruggedly built to withstand the impact of flying debris and constant vibration. Power to the cars is brought in through an overhead catenary and is fed to the underside of the car where the transformer, controls, and propulsion equipment are located. Present voltage is 11 KV, but new electrification is expected to be 25 KV.

Space and weight are critical in this application. There are only about 33 inches above the rail. The width of the transformer is limited by the width of the car.

Only oil- or askarel-insulated units would provide the required performance levels in the space available. As with locomotive applications, present DOT regulations do not restrict the use of flammable liquids, and the use of askarel units has been dictated largely by the economic considerations of fire insurance rates.

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Appendix 3

Types of Askarel-Insulated Capacitors

A. High Voltage Power

Generally AC capacitors are used to improve the power factor of a circuit. Power factor is the ratio of true power in watts to the apparent power as obtained by multiplying the current flowing to the load by the circuit voltage. The power factor correction can be made directly at the load or at utility substations. In the latter case high voltage units will be designed for 4,800 to 13,800 volt service. To the utility engineer the use of capacitors is purely a matter of economics. The main benefits that result from the use of capacitors are:

1. Reduction of losses associated with the delivery of electrical power to the point of use.
2. Reduction of the investment required in equipment for delivering electrical power to the point of use, which may be broken down into:
   a. Reduction of current for the same kilowatt load.
   b. Reduction of the kva rating of equipment required to handle the same kilowatt load.
   c. Reduction of the voltage drop for a given kilowatt load.
   d. Control of delivered voltage if the capacitor kva is varied.

Electric utilities also use capacitor banks in series with distribution circuits to improve voltage regulation. High voltage utility capacitors, low voltage power capacitors, and induction heating capacitors are manufactured at the rate of 200,000 per year, about 2 to 3% of which are for replacements; the balance are for new installations.

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B. Low Voltage Power

Capacitors installed in industrial plants at the demand site (typically large motors and welders) are designed for 230 to 575 volt service. Capacitors installed near the loads are the most efficient way to supply the magnetizing current to produce the flux necessary for the operation of inductive devices. Rates for the sale of power are generally structured to encourage power factor correction at the site, eliminating the need for the electric utility to transmit both power-producing current and magnetizing current all the way from the generator to the plant site.

The same considerations apply to induction heating applications, the principal difference being that capacitors for this rapidly growing application are designed for operation at 960 to 9600 Hz.

C. Lighting

Capacitors improve the efficiency of lighting systems. A fluorescent or mercury vapor lamp can be ballasted without the use of a capacitor, but the power factor of the lighting system would then be in the range of 50 to 60%. For commercial or industrial lighting with either fluorescent or high intensity discharge lamps, the use of a capacitor in the circuit provides part of the lamp ballasting and brings system power factor into the range of 90 to 95%. The current market for these applications is about 44,000,000 units annually of which about 10% are estimated to be replacement ballasts.

D. Air Conditioning

As in the lighting applications, the capacitor improves system efficiency. Air conditioners could be made to operate without capacitors, as do home refrigerators, but because of the higher capacity required for air conditioners, the resultant line/current would virtually eliminate home "plug-ins" and would still further overburden a seriously threatened national

power network. Almost all air conditioner pump motors are of the split-winding type on which the capacitor provides phase differential for the so-called start winding, thus delivering good starting torque. The proper size capacitor permits high (90%) power factor after start-up. The current market for this application is about 12,000,000 units annually, with about 5% of these estimated to be for replacement usage.

E. <u>Industrial Electronics</u>

This market category is a catchall covering many varied applications, two important ones being motor run and power supply applications. Motor run applications are for pumps, fans, and farm feed equipment, and do not differ significantly from air conditioning applications. The power supply market uses capacitors principally to provide high power factor, but through careful design the capacitor can also provide wave shaping where desired. The market is estimated at 23,000,000 units per year with no estimate as to the relative size of the replacement market.

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